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Analysis and validation of the methodology used in the extrapolation of wind speed data at different heights

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A B S T R A C T

The aim of this paper is the analysis of the methodologies and extrapolation laws subsequently used in the calculation of wind speed profiles. It also highlights the disadvantages of using low-sized measurements for creating the wind profile. It also demonstrates how to obtain different speed profiles at the same site and for the same month of a different year. This arrangement allows for the compilation of different roughness and friction coefficients for the same site. This paper also entails a full study case presentation for the site located in the Mexican state of Zacatecas and where the wind speed measurements were extrapolated with a view to estimate the wind power at a specific height.

Contents

1. Introduction

For many centuries to date, wind energy has been used as a source of power for a whole host of purposes. In early days it was used for sailing, irrigation, grain grinding, etc. At the onset of the 20th century, wind energy was put to work on a different use: power generation and electricity-generating wind turbines were produced.

Wind turbines do convert the wind renewable energy into electricity, thus becoming a clean and sustainable power generation alternative. There is a large number and wide assortment of wind turbines which, over time, have evolved in its two key areas: capacity and efficiency. The evolution of wind turbines has been boosted thanks to the growing awareness on environmental issues which in turn stems from an equally growing concern over conventional fossil fuel energy sources. Furthermore, high oil prices and other financial incentives are also bearing their respective weights on the issue. Large-scale wind turbines in

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the range 4–10 MW are now being developed and used for equipping large-scale wind farms worldwide.

The power developed with wind generators depends on several factors with the noteworthy ones being the height above the ground level, the humidity rating and the geographic features of the area but the chief factor is the wind speed. Therefore, the first step in ascertaining the energy that can be produced and the effects of a wind farm on the overall electricity network calls for a thorough understanding of wind itself.

There are different methods used in estimating the wind potential. This paper is aimed at presenting the impact of various methods and models used for extrapolating wind speed measurements and generate a relevant wind speed profile. The results are compared against the real life wind speed readings. Wind resource maps come as a plus factor.

2. Wind power

Each turbine in a wind farm extracts kinetic energy from the wind. The commonplace literature states that real power produced by a turbine can be expressed with the following equation:

$$P = \frac{1}{2}\rho A v^3 c_p \tag{1}$$

where P is the real power in Watts, ρ is the air density in kg/m^3, A is the rotor area in m^2, v is the wind speed in m/s, and c_p is the power coefficient [1]. Air density is a function of temperature, altitude and, to a much smaller extent, humidity. The power coefficient is simply the ratio of power extracted by the wind turbine rotor to the power available in the wind. This data is supplied in tabular and, sometimes, graphical formats.

Since the power developed is proportional to the cube of wind speed, wind power production is highly dependent on the wind speed resources; thus an understanding of the wind speed variability is crucial if we are to determine the wind resources available at each wind farm location.

3. Factors influencing wind speeds

Empirical evidence has shown that at a great height over the ground surface (in the region of 1 km) the land surface influence on the wind is negligible. However, in the lowest atmospheric layers the wind speed is affected by ground surface friction factors [2].

Local topography and weather patterns are predominant factors influencing both wind speed and wind availability. Differences in altitude can produce thermal effects. Usually the wind speed increases with altitude, so hills and mountains may come close to the high wind speed areas of the atmosphere. There is also an acceleration of wind flows around or over hills and the funnelling effect when flowing through ravines or along narrow valleys. On the other hand, artificial obstacles can affect wind flows. In short, there are two well-defined factors affecting wind speed: *environmental factors*, ranging from local topography, weather to farming crops, etc. and *artificial factors* ranging from man-made structures to permanent and temporary hindrances such as buildings, houses, fences and chimneys.

Natural or man-made topographical obstacles interfere with the wind laminated regime. A low level disruption will cause the wind speed to increase in the higher layers and drop in the opposite layers. In urban areas, a different situation arises: the so-called "island of heat"; an effect that will produce local winds. Due to this island of heat effect, the wind measurement readings at urban meteorological stations are not useful for predicting the wind patterns in other areas adjacent to large conurbations [3].

The profile of average wind speed at one site is the representation of the wind speed variations in line with the height or distance of the site. Fig. 1 compares wind profiles at the CNA measurement station (CNA, "Comisión Nacional del Agua") in Guadalupe, Zacatecas during a 4-month period; in it we

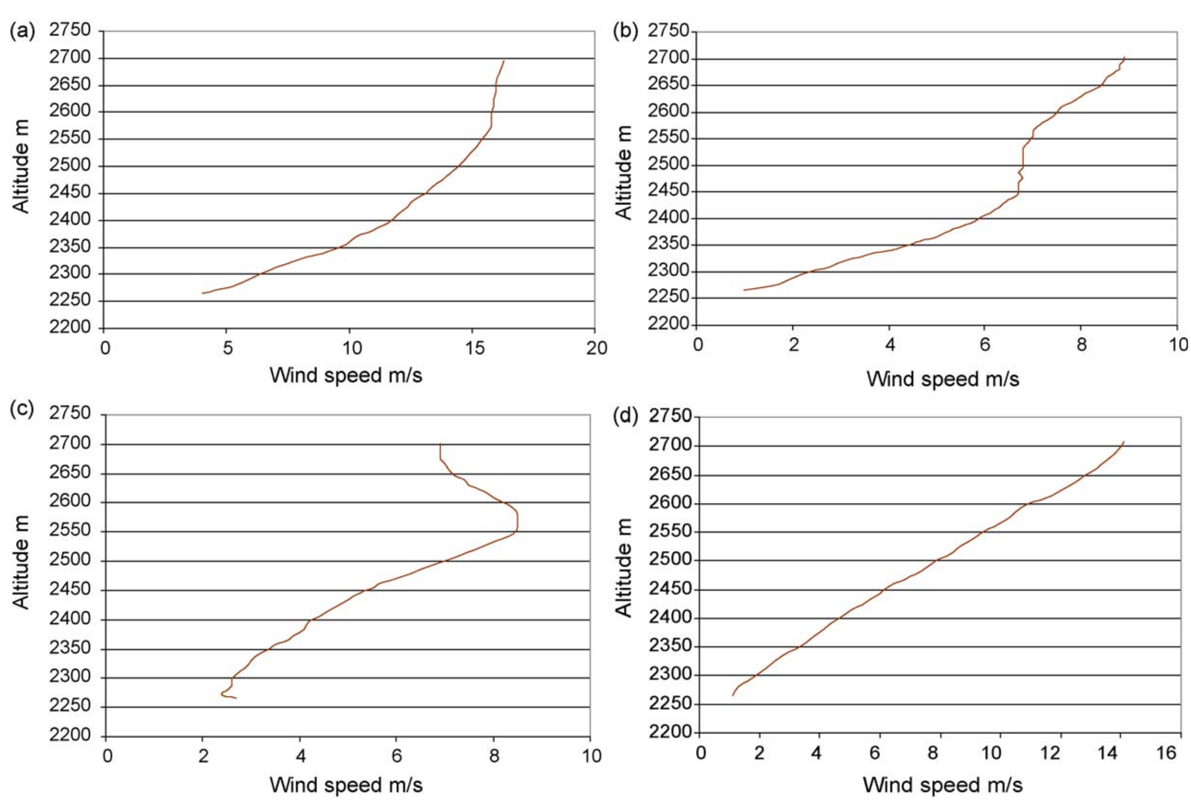

Fig. 1. Typical wind profile monitored at the station of CNA in Guadalupe, Zacatecas during the months of (a) January; (b) May; (c) July; and (d) November.

can see a display of the profile variations in the months concerned [4]. We have noted also that, usually, the wind profile repeats itself year-on-year.

4. Wind speed calculations at varying heights

The initial measurements are generally taken at some 10-m heights [1,5], although there are data capture undertaken at lower heights and for other purposes such as agricultural monitoring. The commonly used technique is to estimate speeds at higher altitudes and extrapolate the readings obtained and build-up the site's wind speed profile.

There are sundry theoretical expressions used for determining the wind speed profile. The Monin–Obukhov method is the most widely used to depict the wind speed v at height z by means of a log-linear profile clearly described by:

$$v(z) = \frac{v_f}{K}\left[\ln\frac{z}{z_0} - \xi\left(\frac{z}{L}\right)\right] \tag{2}$$

where z is the height, v_f is the friction velocity, K is the von Karman constant (normally assumed as 0.4), z_0 is the surface roughness length, and L is a scale factor called the Monin–Obukhov length. The function $\xi(z/L)$ is determined by the solar radiation at the site under survey. This equation is valid for short periods of time, e.g. minutes and average wind speeds and not for monthly or annual average readings.

This equation has proven satisfactory for detailed surveys at critical sites; however, such a method is difficult to use for general engineering studies. Thus the surveys must resort to simpler expressions and secure satisfactory results even when they are not theoretically accurate [5]. The most commonly used of these simpler expressions is the Hellmann exponential law that correlates the wind speed readings at two different heights and is expressed by:

$$\frac{v}{v_0} = \left(\frac{H}{H_0}\right)^{\alpha} \tag{3}$$

In which v is the speed to the height H, v_0 is the speed to the height H_0 (frequently referred to as a 10-m height) and α is the friction coefficient or Hellman exponent. This coefficient is a function of the topography at a specific site and frequently assumed as a value of 1/7 for open land [1,6,7]. However, it must be borne in mind that this parameter can vary for one place with 1/7 value during the day up to 1/2 during at night time [8]. Eq. (3) is also known as the power law when the value of α is equal to 1/7 is commonly referred to as the *one-seventh power law*.

Provided there are no significant ground level obstacles, the friction coefficient α (Eq. (3)) is set empirically and the equation can be used to adjust the data reasonably well in the range of 10 up to 100–150 m. The coefficient varies with the height, hour of the day, time of the year, land features, wind speeds and temperature. All such findings have emerged from the analysis undertaken at several locations worldwide [9–11]. Table 1 shows the friction coefficients of various land spots that, in each case, are given in function of the land roughness [1,7,12].

Table 1
Friction coefficient α for a variety of landscapes.

Landscape type	Friction coefficient, α
Lakes, ocean and smooth hard ground	0.10
Grasslands (ground level)	0.15
Tall crops, hedges and shrubs	0.20
Heavily forested land	0.25
Small town with some trees and shrubs	0.30
City areas with high rise buildings	0.40

Another formula, known as the logarithmic wind profile law and which is widely used across Europe, is the following:

$$\frac{v}{v_0} = \frac{\ln(H/z_0)}{\ln(H_0/z_0)} \tag{4}$$

where z_0 is called the roughness coefficient length and is expressed in metres, and which depends basically on the land type, spacing and height of the roughness factor (water, grass, etc.) and it ranges from 0.0002 up to 1.6 or more. These values can be found in the common literature [1,2]. In addition to the land roughness, these values depend on several factors: they can vary during the day and at night and even during the year. For instance the reading or monitoring stations can be within farming land; it follows that the height/length of the crops will change. However, once the speeds have been calculated at other heights, the relevant equations can be used for calculating the power or average useful energy potential via different methods such as Weibull or Rayleigh distributions. The specialist software package available for calculating such data is known as WAsP©.

Something worth highlighting is that z_0, for a homogeneous land, can be obtained by means of measurements at two different heights. Once this new z_0 is to hand, it becomes very straightforward to calculate the speed at other heights and the speed profile would be the one expressed by Eq. (3), thus turning calculations into a much simpler task [13].

It is also important to consider that as well as a wind compass rose is used for tracing the map of the amount of energy coming from different directions, a roughness rose is often created for a given site and where the roughness is specified for each directional sector. For each sector an estimate of the roughness is assumed, with a view to estimate how the wind speed does change in each sector due to the varying land roughness [2].

It is quite common to extract from the tables a rated value of such roughness factor. However, when these factors are compared against factor calculations you can conclude that the factors shown in the tables are not always accomplished. The common literature is fairly prolific on roughness coefficients used with Tables 2–4 being the most commonly used. From the tables it is easy to note the differences among them, and a good sample of such differences is the value allocated to large cities and sizable forest areas.

A way forward that allows us to obtain fairly reliable friction and roughness coefficients is to undertake estimates in similar places (proximity and environmental conditions' wise) is to register the wind speed readings from at least two different heights during a reasonable length of time. The friction coefficient α is firstly obtained for two different heights and speeds using Eq. (3), and then by using Eqs. (3) and (4) with the roughness coefficient z_0 being obtained via:

$$z_0 = \exp\frac{H_0^{\alpha}\ln H - H^{\alpha}\ln H_0}{H_0^{\alpha} - H^{\alpha}} \tag{5}$$

Table 2
Roughness classes and lengths [1].

Roughness class	Description	Roughness length, z (m)
0	Water surface	0.0002
1	Open areas dotted with a handful of windbreaks	0.03
2	Farmland dotted with some windbreaks more than 1 km apart	0.1
3	Urban districts and farmland with many windbreaks	0.4
4	Densely populated urban or forest areas	1.6

Table 3
Roughness lengths for varying landscape types [13].

Land features	z_0 (mm)
Very soft; ice or mud	0.01
Calm open seas	0.20
Chopped high seas	0.50
Snow Surface	3.00
Grassland and green areas	8.00
Pasture areas	10.00
Arable land	30.00
Annual crops	50.00
Scant trees	100.00
Heavily forested areas and few buildings	250.00
Forest land covered with large-size trees	500.00
City outskirts	1500.00
Downtown city areas with plenty of high rise buildings	3000.00

Both friction α and ruggedness z_0 coefficients are completed for two different measurements and then it becomes feasible to depict the corresponding wind profile and relevant factors for one day, time and year for different wind directions [9,10].

There are locations where it is difficult to match these factors or the results appear to be wrong because they do not show very reliable data. These locations are usually in mountain ranges where, according to national and international recommendations, it makes sense to take the readings at several altitudes during a reasonable length of time.

In 1947 Frost [14] proved that Eq. (3) with a value of $\alpha = 1/7$ described good atmospheric wind profiles for heights ranging from 1.5 and 122 m during almost neutral conditions (adiabatic). However, this data indicates that the values of α drop with the heat (unstable conditions) and increase with a land cooling down cycle (stable conditions). Nowadays the atmosphere trends, below the 10 m mark, are illustrated easily by means of flux–gradient relationships whenever the land surface features and the momentum fluxes and heat have known values.

5. Case studies

With a view to show the effectiveness of the extrapolation methods in securing a wind profile, three case studies are thoroughly scrutinised. In such case studies the information shown stems from the monitoring stations at different altitudes. Measurements are used for calculating the wind speeds using the exponential Hellmann law Eq. (3) and the logarithmic law profile Eq. (4).

Table 4
Roughness classes and lengths considered by the Danish Wind Industry Association [2].

Roughness class	Roughness length (m)	Landscape type
0	0.0002	Water surface.
0.5	0.0024	Completely open ground with a smooth surface, e.g. concrete runways at the airports, mowed grassland, etc.
1	0.03	Open farming areas fitted with no fences and hedgerows and very scattered buildings. Only softly rounded hills.
1.5	0.055	Farming land dotted with some houses and 8 m tall sheltering hedgerows within a distance of some 1250 m.
2	0.1	Farming land dotted with some houses and 8 m tall sheltering hedgerows within a distance of some 500 m.
2.5	0.2	Farming land dotted with many houses, shrubs and plants, or with 8 m tall sheltering hedgerows of some 250 m.
3	0.4	Villages, hamlets and small towns, farming land with many or tall sheltering hedgerows, forest areas and very rough and uneven terrain
3.5	0.8	Large cities dotted with high rise buildings.
4	1.6	Very large cities dotted with high rise buildings and skyscrapers.

Table 5
Average wind speeds broken down by urban areas.

Height	15 m	32 m	60 m
Measured speed [m/s]	9.3	10.557	–
Calculated speed [m/s] with α	–	10.5568	11.7277
Calculated speed [m/s] with z_0	–	10.5563	11.5994

5.1. Base case

This case was extracted from the paper published by Jaramillo and Borja [9] in which the average registered annual speeds in year 2001 – at 15 and 32 m above ground level – were 9.3 and 10.557 m/s, respectively. According to such data the friction coefficient α is 0.1673 and the roughness coefficient z_0, is 0.055. These coefficients are used for calculating wind speeds at 32 and 60 m. The calculated and measured average speeds are shown in Table 5, with a difference in the estimated speed at 60 m with the calculated coefficients α and z_0.

The wind profile obtained from Eqs. (3) and (4) is almost coincidental in the lowest heights but, as shown in Fig. 2, when going over the 35-m ceiling, the wind speed value differences start to show up. It is clear that calculated coefficients operate well for the first extrapolation but have a poor accuracy rating for speeds at higher altitudes.

5.2. Case study: urban areas

In this case we considered the data from two different monitoring stations located in the main Universidad Nacional Autónoma de México (UNAM) campus, one of them known as DGSCA and the other referred to as JARBO [15].

As regards the DGSCA station, the data was measured along a time horizon of 15 months at 10-min intervals using two anemometers at 20 and 30 m over the roof level of a building which is some 15 m high and surrounded with vegetation whose altitude is some 15 m over the roof level.

The JARBO station readings were taken over 11 months at 10-min intervals and using 3 anemometers located at 20, 30 and 40 m above ground level.

The procedure entailed using the readings for calculating the exponent α for two different heights and then secure the

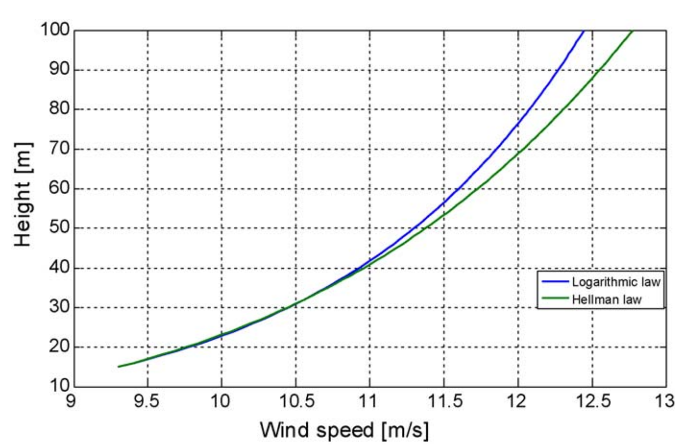

Fig. 2. Wind profile built up using the logarithmic law and the Hellman law applicable to rural areas.

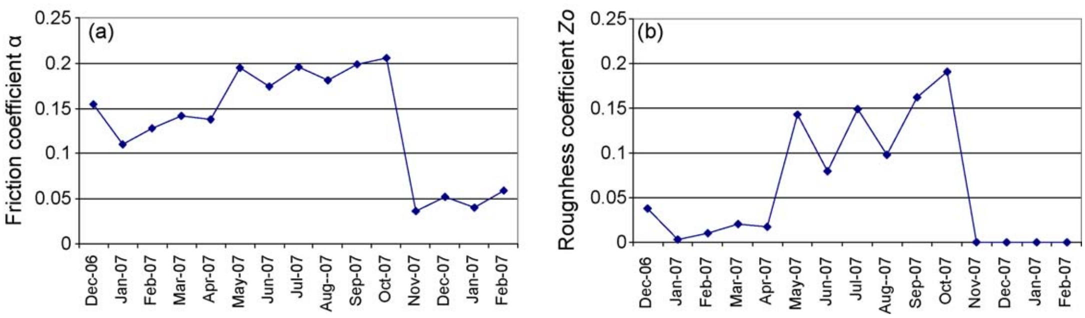

Fig. 3. Variation of the (a) friction coefficients and (b) roughness coefficients, at the DGSCA station.

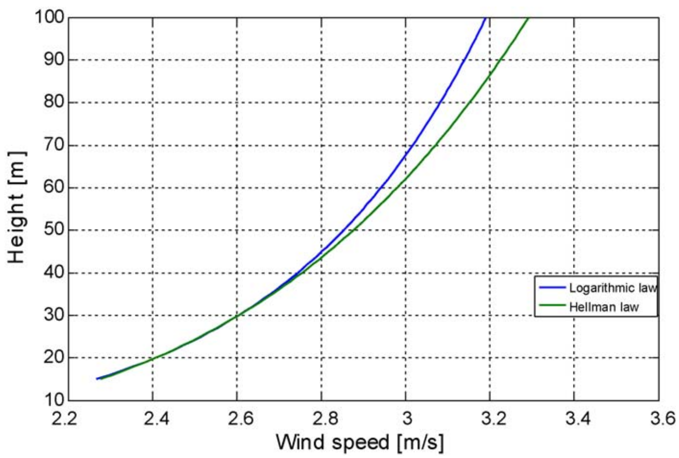

Fig. 4. Wind profile build-up for May 2007 using the logarithmic law and the Hellman law for urban areas at the DGSCA station.

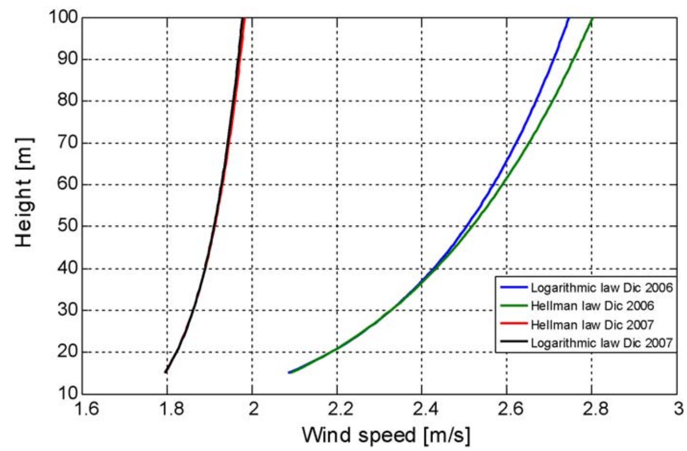

Fig. 5. Comparison of wind profiles for the months of December 2006 and December 2007, compiled with the use of the logarithmic law and the Hellman law for case study B, with all data captured at the DGSCA station.

roughness coefficient z_0 using Eq. (5). The graphic results for both coefficients of the DGSCA station are shown in Fig. 3.

As you may have noted from the previous graphs, the roughness coefficient gets to values very close to zero and it is also distinctly obvious the sharp variations experienced in the roughness and friction coefficients during January and February in 2 different serial years. Thus, this case attracts very special attention and a considerable error will arise when managing average coefficients. For instance, during the month of May and using Eqs. (3) and (4), the estimated wind profile would be the one shown in Fig. 4. Likewise, Fig. 5 shows the wind profiles for December 2006 and 2007 highlights that although it is the same month for 2 consecutive years, the readings showed different wind average speeds and profiles.

Looking at the JARBO station case – and resorting to the same procedure as with the DGSCA station case – friction coefficients were obtained for 20 and 30 m (α_1), then for 20 and 40 m (α_2) and finally for 30 and 40 m (α_3). Such friction coefficients were then used to work out the respective roughness coefficients and their average values. The outcome is shown in Fig. 6.

Furthermore, Fig. 6 shows that the variation of the two monthly average coefficients is remarkable. This is an issue we need to address since it would indicate that the extrapolation method is not the right one or is inconsistent when it comes to sites located

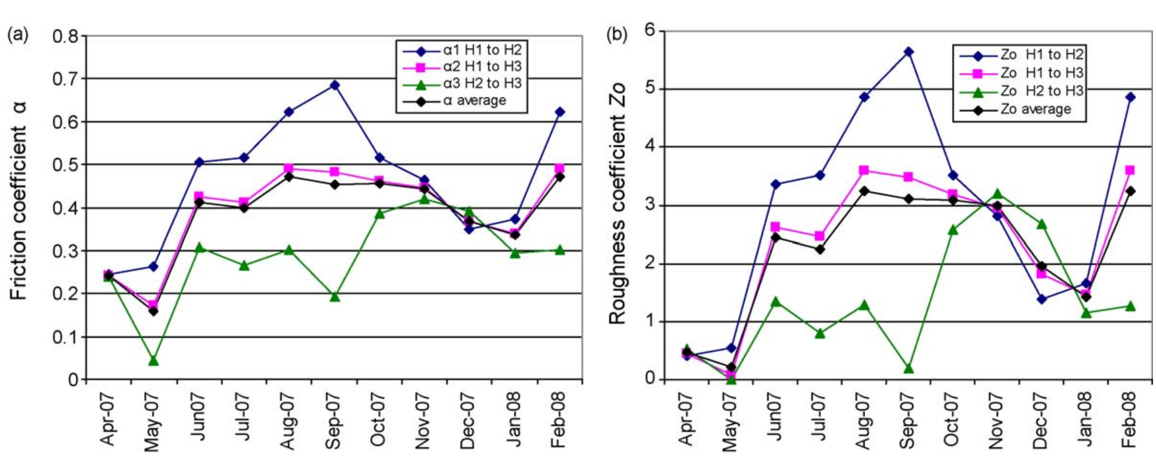

Fig. 6. Variation of the (a) friction coefficients and (b) roughness coefficients for the JARBO station.

within urban areas. The wind profiles for this case are more complex. Indeed Fig. 7 presents the average wind profiles for 2 different months together with the coefficients' average values. This finding illustrates that wind energy calculation errors using a friction coefficient of 1/7 could become quite significant.

For completeness sake, Fig. 8 shows the wind resource maps for the JARBO station referred to wind speed and power density at 20 m high. The wind speed obtained in this area ranges from 1.70 to 2.38 m/s and the wind power variation goes from 7 to 18 W/m^2, which can hardly make a case for installing a wind turbine.

5.3. Case study: rural areas

In this case, the surveyed data stems from measurements taken at a monitoring station located in the UAA-UAZ rural and farming area [16,17]. These readings were taken at three different altitudes, namely 3, 20 and 40 m above ground level. Three friction coefficients were obtained from this data while resorting to Eq. (3) at 3 and 20 m (α_1), at 3 and 40 m (α_2) and, finally, at 20 and 40 m (α_3). With these friction coefficients the relevant roughness coefficients and their average values were calculated using Eq. (5).

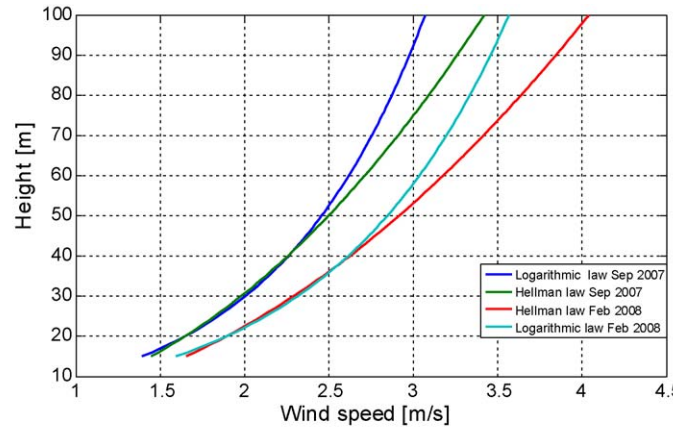

Fig. 7. Comparison of the wind profile for the months of September 2007 and February 2008 compiled using the logarithmic law and Hellman law for case study B, with all data captured at the JARBO station.

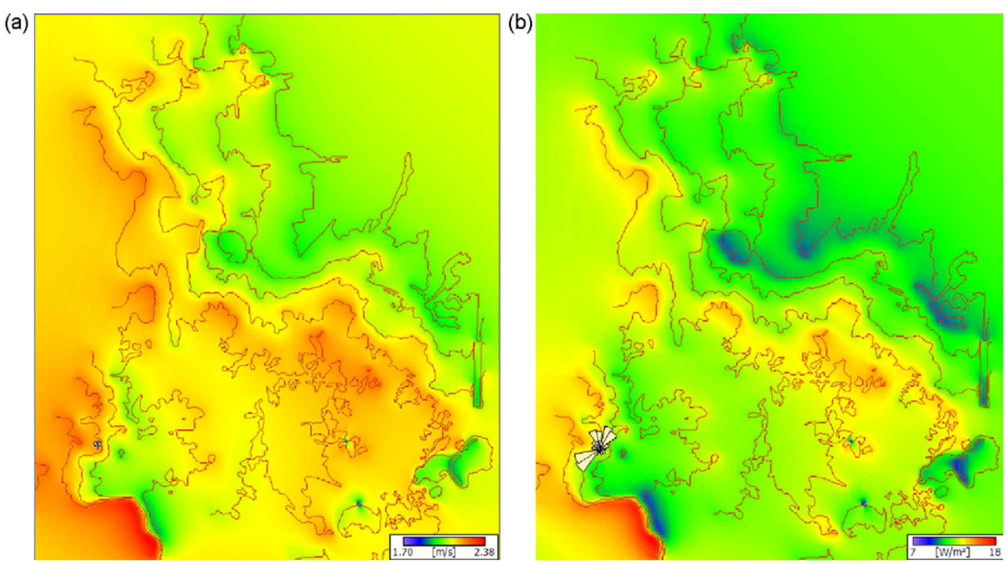

Fig. 8. Wind resource maps for (a) wind speed and (b) power density at the JARBO station produced with the use of the WAsP package.

Table 6
Data and results for average friction and roughness coefficients in rural areas.

Month	V_1 (1)	V_2 (2)	V_3 (3)	α_1 (4)	α_2 (5)	α_3 (6)	z_0 (7)	z_0 (8)	z_0 (9)
August 2005	2.02	3.92	4.25	0.350	0.287	0.117	0.400	0.288	0.005
September 2005	2.53	4.55	5.03	0.309	0.265	0.145	0.279	0.218	0.028
October 2005	2.22	3.99	4.47	0.309	0.270	0.164	0.278	0.233	0.063
November 2005	2.04	3.78	4.34	0.325	0.292	0.199	0.325	0.302	0.186
December 2005	1.75	3.66	4.14	0.387	0.331	0.178	0.521	0.445	0.101
January 2006	2.20	4.18	4.63	0.337	0.286	0.148	0.360	0.284	0.032
February 2006	2.23	4.10	4.62	0.321	0.281	0.172	0.312	0.268	0.085
March 2006	2.92	4.83	5.47	0.265	0.242	0.180	0.165	0.155	0.107
April 2006	2.71	4.39	4.9	0.252	0.227	0.159	0.137	0.119	0.051
May 2006	2.63	4.34	4.85	0.264	0.236	0.160	0.162	0.139	0.055
June 2006	3.06	4.77	5.21	0.234	0.205	0.127	0.100	0.075	0.011
July 2006	2.84	4.40	4.91	0.231	0.211	0.158	0.095	0.086	0.051
Annual average	2.43	4.24	4.73	0.299	0.261	0.159	0.261	0.218	0.065

Notes: (1) Speed averages, at H_1 = 3 m, in m/s. (2) Speed averages, at H_2 = 20 m, in m/s. (3) Speed averages, at H_3 = 40 m, in m/s. (4) Friction coefficient, monthly average using measurements at H_1, H_2, V_1, V_2 and Eq. (3). (5) Friction coefficient, monthly average using measurements at H_1, H_3, V_1, V_3 and Eq. (3). (6) Friction coefficient, monthly average using measurements at H_2, H_3, V_2, V_3 and Eq. (3). (7) Roughness coefficient, monthly average using measurements at H_1, H_2, V_1, V_2 and Eq. (5), in m. (8) Roughness coefficient, monthly average using measurements at H_1, H_3, V_1, V_3 and Eq. (5), in m. (9) Roughness coefficient, monthly average using measurements at H_2, H_3, V_2, V_3 and Eq. (5) in m.

Table 7
Wind speed data and readings when applying average friction and roughness coefficients in rural areas.

Month	α monthly average (1)	Speed to 20 m (m/s) (2)	Speed to 40 m (m/s) (3)	Speed to 40 m (m/s) (4)	z_0 monthly average (5)	Speed to 20 m (m/s) (6)	Speed to 40 m (m/s) (7)	Speed to 40 m (m/s) (8)
August 2005	0.251	3.25	3.87	4.67	0.231	3.51	4.06	4.53
September 2005	0.240	3.99	4.71	5.37	0.175	4.22	4.84	5.22
October 2005	0.248	3.55	4.22	4.74	0.191	3.75	4.31	4.58
November 2005	0.272	3.42	4.13	4.56	0.271	3.65	4.24	4.39
December 2005	0.299	3.10	3.81	4.50	0.356	3.32	3.89	4.29
January 2006	0.257	3.59	4.29	4.99	0.225	3.82	4.41	4.83
February 2006	0.258	3.64	4.35	4.90	0.222	3.85	4.45	4.73
March 2006	0.229	4.51	5.28	5.66	0.142	4.74	5.40	5.51
April 2006	0.213	4.07	4.72	5.09	0.102	4.25	4.80	4.97
May 2006	0.220	3.99	4.65	5.06	0.119	4.18	4.74	4.93
June 2006	0.189	4.38	4.99	5.44	0.062	4.56	5.11	5.34
July 2006	0.200	4.15	4.77	5.05	0.077	4.31	4.85	4.95
Annual average	0.240	3.80	4.48	5.00	0.181	4.01	4.59	4.85

Notes: (1) Friction coefficient, monthly average using α_1, α_2, α_3 (from Table 6). (2) Calculated speed with friction coefficient α_1 (from Table 6). (3) Calculated speed with friction coefficient α_2 (from Table 6). (4) Calculated speed with friction coefficient α_3 (from Table 6). (5) Roughness coefficient, monthly average using columns (8), (9) and (10), in m. (from Table 6). (6) Calculated speed with roughness coefficient z_0 for H_1, H_2, V_1, V_2 (from Table 6). (7) Calculated speed with roughness z_0 for H_1, H_3, V_1, V_3 (from Table 6). (8) Calculated speed with roughness z_0 for H_2, H_3, V_2, V_3 (from Table 6).

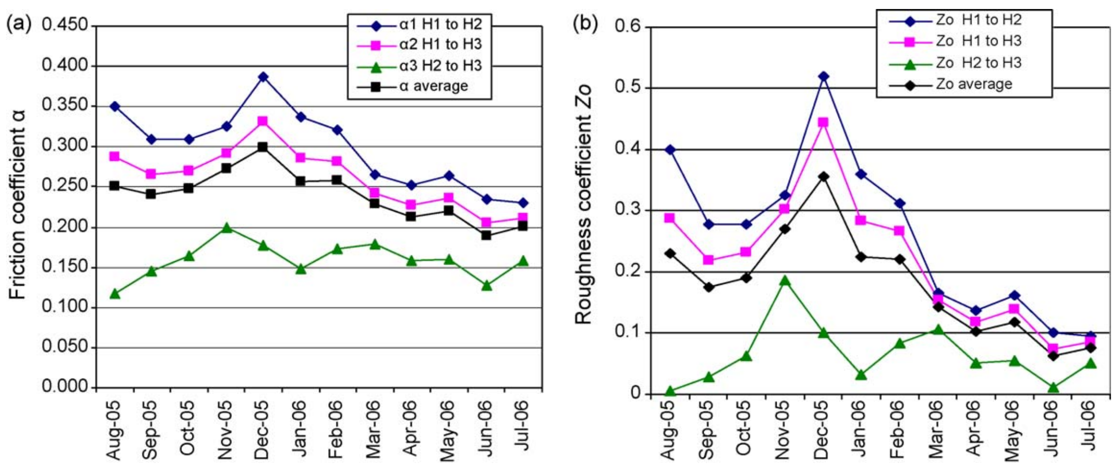

Fig. 9. Variation of (a) the friction coefficient and (b) the roughness coefficient in rural areas at different heights.

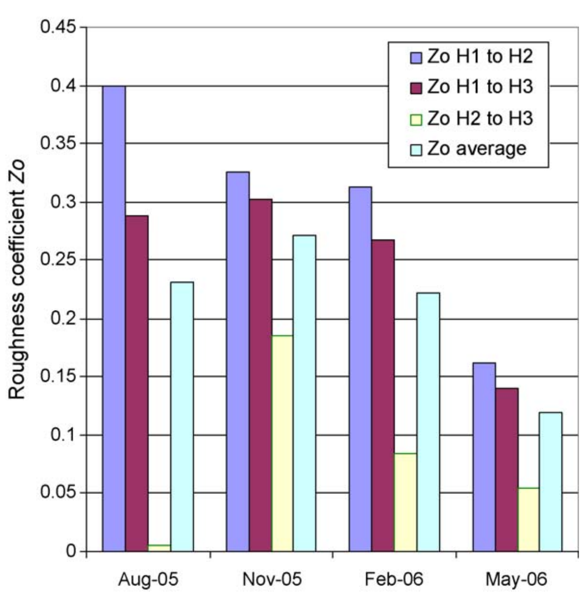

Fig. 10. Roughness coefficient for August 2005, November 2005, February 2006 and May 2006.

Thereafter we calculated the annual average values for the friction and roughness coefficient at 0.240 and 0.181 m, respectively. The average speeds of every month and the annual average were calculated with the use of both friction and roughness coefficients.

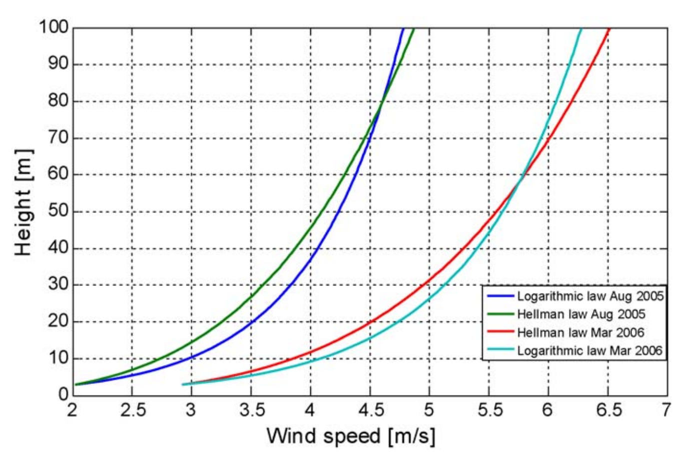

Fig. 11. Comparison of wind profiles for the months of August 2005 and March of 2006 compiled with the use of the logarithmic law and the Hellman law for rural areas, all data captured at the UAA-UAZ station.

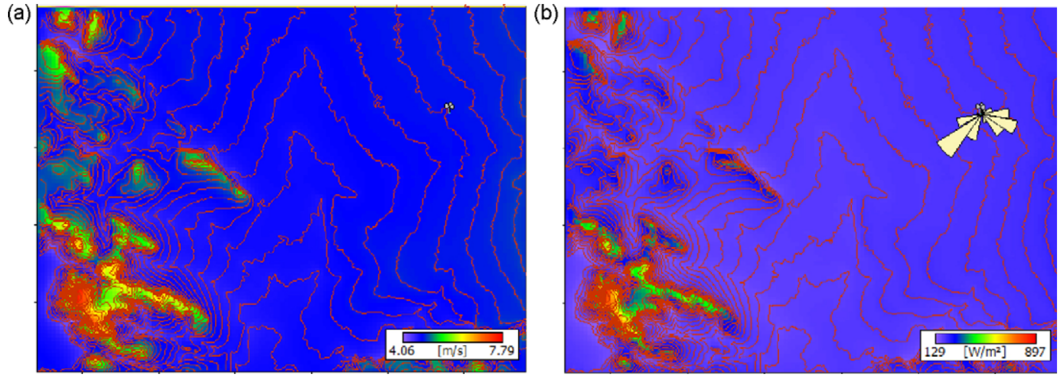

Fig. 12. Wind resource maps for (a) wind speed and (b) power density at the UAA-UAZ station with all data captured with the WAsP package.

We then undertook a comparison between calculated and measured data at 20 and 40 m high and we identified some variations. Tables 6 and 7 show the sets of calculated and measured data as well as highlighting the differences between them; in some cases in excess of 8%, as shown in the average speed columns calculated for 40 m (V_3 in August, column 4 from Table 6 and column 5 from Table 7) with both friction and roughness coefficients at the H_1 and H_3 altitudes.

Fig. 9 shows for this case the variation experienced by the friction and roughness coefficients. The variation of the roughness coefficient for the height included in the analysis and for a specific month is also very noticeable (Fig. 10).

As it can be concluded from the data captured in the foregoing figures, in some cases there are important variations when using either average values for the roughness or friction coefficients; it is also noticeable that they experience changes throughout the season or month and with land altitudes.

In this case the wind profiles for both August-2005 and March-2006 on a 3-m-high basis are shown in Fig. 11. The wind resource maps encompassing the wind speed and power density at this station are shown in Fig. 12. These maps are for a height of 80 m.

From Fig. 12 it can be noted that the wind speed data obtained in this zone fluctuates between 4.06 and 7.79 m/s whereas the power density ranges from 129 and 897 W/m^2; thus pointing out that using wind power here is a viable proposition.

6. Conclusions

This work focuses on the use of scientific findings and predefined coefficients for calculating the wind speed at different heights. Moreover, these findings must be pondered carefully because – as this work demonstrates – these coefficients are heavily dependent on the relevant land features.

Since the wind speed undergoes repeated changes and the roughness and friction coefficients also change in line with the landscape features, the time of the day, the temperature, height, wind direction, etc. it follows that the reading results (when extrapolating such wind speed data for a specific reference height) should be pondered carefully and taken with a pinch of salt.

This assumption is further enhanced by the basic hard facts that whenever we use a single equation or we have not identified the prevailing parameters on the site where the measuring instrument are placed, we could easily end up with misleading values or be far from their true values. Needless to say these wrong readings and assumptions will lead us to wrong estimates of the wind energy potential.

The formulas and scientific findings can be used as initial estimates of the wind potential to be had at the desired altitudes. Such initial estimates do lead us to consider the necessity of an international standard to be applied and coupled with the necessary exceptions in each case. In real life and to sum up, there is no better substitute to actual site measurements.

This sort of surveys and analytical work are the initial steps prior to mounting the masts and towers fitted with either precision measuring instruments or wind generators. Indeed an analysis of this kind would help to save money and time that otherwise – i.e. in the absence of the appropriate methodology – would be totally wasted.

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